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REFLECTION CHARACTERISTICS OF ARTIFICIAL SATELLITES CONSTRUCTED IN THE FORM OF INFLATED POLYHEDRONS

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SUMMARY

Tests were made of inflated polyhedral shapes of thin aluminum-coated plastic to determine their suitability as artificial earth satellites having enhanced visibility as a result of bright flashes of reflected light from the facets. It was found that a polyhedron with 12 major faces, when inflated as a simple balloon, gave about one flash per revolution about a random axis when illuminated by a light representing the sun. As a result of the bulging of the facets, the brightness of these flashes was only about three times greater than that from an equivalent sphere, which is much less than the theoretical brightness from a polyhedron having optically flat facets.

INTRODUCTION

In order to obtain the maximum amount of information from artificial earth satellites, it is desirable that optical tracking, both photographic and visual, be as complete as possible. It is therefore desirable that these satellites be as conspicuous as possible. In reference 1 it was suggested that a rotating satellite in the form of a faceted specular sphere would give random bright flashes from reflected sunlight, thus improving the visibility of the satellite. It is shown in this reference that a polyhedron having 428 optically flat faces should average one flash of reflected sunlight per revolution for any given observer. These flashes would be more than a thousand times brighter than the steady reflection from a sphere of the same surface area.

The purpose of this paper is to present the results of a brief investigation into the feasibility of constructing satellites in the form of inflatable polyhedrons which have suitable reflection characteristics. It was recognized that the facets of such a satellite would not be optically flat but would bulge outward somewhat under the inflating pressure. This bulging would have two interrelated effects: First, the light reflected from any one facet would be spread over a larger solid angle than that reflected from an optically flat facet, and second, the brightness of the reflection seen from only one facet would be lessened. Because of the first effect, a smaller number of facets would be required to produce a given number of flashes per revolution, since the path swept out by the light reflected from a facet would be wider. In regard to the second effect, the brightness of the reflection from a spherical surface is proportional to the square of the radius of curvature. The reflection from the bulging facets would therefore still be brighter than that from a sphere of equivalent volume, since the radius of curvature of the facets would be greater than that of an equivalent sphere. The purpose of the tests reported was to obtain some idea of the magnitude of these effects. It was arbitrarily decided that a desirable configuration should give roughly one reflection per revolution about a random axis. This flash repetition rate has been chosen arbitrarily as "optimum" since it is not within the scope of this paper to discuss all the variables which would determine the optimum rate for a real satellite.

MODELS AND PROCEDURE

The models used for the tests were constructed as simple "balloons" of thin sheet material about 0.001 inch thick. About one-third of this thickness was Mylar plastic; the rest (outer surface) was aluminum foil. A series of models was first made in order to get some idea of the optimum configuration. These models were based on regular and semiregular polyhedrons having from 12 to 32 faces.

The inflated models were supported by the airstream from an electric fan aimed vertically. It was found that when supported in the airstream, the model rotated about an axis that was constantly changing with respect to the model, although this axis did not depart more than about 30° from the vertical. This method of suspension caused very little distortion in the shape of the model.

The models were illuminated by a spotlight in a darkened room and a photocell was used to pick up the reflection from the model. The angle between the spotlight and the photocell as seen from the model was 90°. The signal from the photocell was fed into a direct-current amplifier and then to a dual-channel recording galvanometer. The response of this system was linear. A manually operated switch was used to feed blips into the second channel in order to note revolutions of the model as counted by the observer with the aid of a small mark on the model.

RESULTS OF PRELIMINARY TESTS

A series of preliminary models was tested in order to determine the optimum configuration. These models were checked for approximate radius of curvature of the faces by means of templates, and some light-reflection measurements were made. A 32-faced truncated icosahedron (12 pentagonal and 20 hexagonal faces of approximately equal area) was found to be too nearly spherical when inflated. The measured radius of curvature of the faces was about 1.5 times that of the equivalent sphere. Figure 1 shows a typical galvanometer trace for this model. The short vertical marks on the zero reference line are the revolution markers. The average line shown was obtained by integrating the area under the curve. The peak reflections reach a value of about twice the average. Based on the measured radius of curvature of the faces, the calculated peak reflections should be 2.25 times that of an equivalent sphere. This model was eliminated from further consideration because the flash repetition rate was too high and the flash brightness too low.

A 20-faced model (a regular icosahedron) was also found unsuitable because the triangular shape of the facets resulted in a very distorted surface which did not approximate a spherical surface. This distorted shape spread the light reflected from a facet over a wide angle, thus reducing the brightness of the individual facets.

Preliminary tests of a regular dodecahedron (12 pentagonal faces) indicated that this shape was near the optimum for this type of model construction. It was concluded from the preliminary tests that the model should have about 12 major facets and that the facets should have as many sides as possible; that is, they should approximate circles. Facets with a small number of sides, such as triangles, were found to have distorted surfaces with small radii of curvature, resulting in low-intensity reflections. Consequently, for the final tests, a dodecahedron shape was modified into a truncated dodecahedron by cutting off the 20 vertices, thus forming 12 large 10-sided faces and 20 small triangles. A pattern for half of this model is shown in figure 2. This model was designed to have the same surface area as a sphere 30 inches in diameter. A spherical model 30 inches in diameter constructed of 36 lunes was used for comparison. The two models were made of the same aluminum-Mylar material, but because of differences in construction techniques, the polyhedral model had a considerably more crinkled surface. Figure 3 is a photograph of these models. Reflection measurements were made for this faceted model and for the reference sphere.

RESULTS AND DISCUSSION

Measurement of Reflection

A typical portion of the galvanometer trace for the faceted model and the reference sphere is shown in figure 4. Figure 4(a) indicates the random nature of the bright reflection from the faceted model. The higher peaks are about three times the average value for this model. The measured radius of the major facets was about twice that of the reference sphere; thus, the calculated reflection level from these faces is four times that of the reference sphere. The crinkled nature of the surface probably accounts for the difference between the calculated and the measured reflection. The minimum reflection intensity is a little more than half of the average.

The jagged nature of the trace for the reference model (fig. 4(b)) shows that this model is by no means a perfect sphere. The lunes apparently remain somewhat flattened and give reflections occasionally over twice as bright as the average value. The minimum reflection is less well defined than for the faceted model, but appears to be about half of the average. The average reflection intensity for the two models agrees within about 5 percent, which is probably within the experimental accuracy of the method.

It is seen that although there is some gain from the use of a simple inflated multifaceted satellite as compared to a sphere, the gain is not great and is much less than would be obtained from optically flat faces. For example, a polyhedron with 428 accurately flat reflecting facets should give flashes about 1,400 times as bright as the reflection from a sphere. If the flashes from the comparison sphere were rapid enough so that the average light value was seen, then the faceted model would give roughly one flash per revolution having an intensity three times that of the comparison sphere. Since the human eye and photographic emulsion both have an approximate logarithmic response, a factor of 3 in intensity is not likely to be very significant. In between these flashes there would be other flashes of somewhat lower intensity, but the brightness would not drop below about half the value of that for the comparison sphere.

Construction Considerations

A faceted type of construction offers some possibility of weight saving as a result of the reduction of seam length over that for the lune type of sphere construction. A faceted shape could have about 300 faces before the total seam length became equal to that for a sphere constructed of 36 lunes.

A polyhedron of 92 faces (12 pentagons, 80 hexagons) would probably be very nearly spherical when inflated and would have only about 55 percent of the seam length of a 36-lune sphere.

Some consideration was given to the possibility of constructing polyhedrons supported by a series of inflatable tubes running along the edges. Although brief tests of a simple model constructed in this manner were not encouraging, the tests were not extensive enough to warrant any conclusions.

CONCLUDING REMARKS

Tests were made of inflated polyhedral shapes of thin aluminum-coated plastic to determine their suitability as artificial earth satellites having enhanced visibility as a result of bright flashes of reflected light from the facets.

Assuming that the desired flash rate is one per revolution, it was found that the optimum shape for a simple balloon type of construction was a polyhedron with 12 major faces. It was found that when the model was rotated about a random axis and illuminated by a light representing the sun, an observer would see roughly one bright flash per revolution of the model. The brightness of these flashes was about three times the brightness of the reflection from a reference sphere. Since the human eye and photographic emulsions both have an approximately logarithmic response, this gain cannot be considered very significant and is much less than would be obtained from optically flat faces. The minimum brightness was about half that of the reference sphere and the average value was about the same as the average of the reference sphere.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., August 25, 1959.

REFERENCE

1. Wilson, Raymond H., Jr.: Theory of a Polyhedral Heliotrope on an Artificial Satellite. Astronomische Nachrichten, Bd. 284, Heft 2, 1957, pp. 79-82.

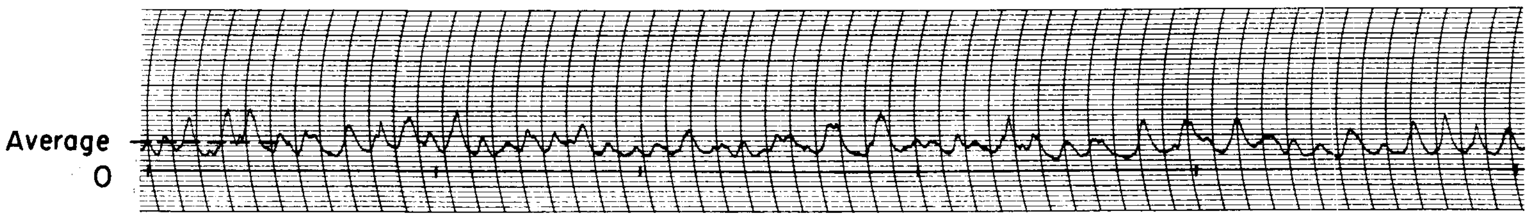

Figure 1.- Galvanometer trace of light reflection from a 32-faced truncated icosahedron.

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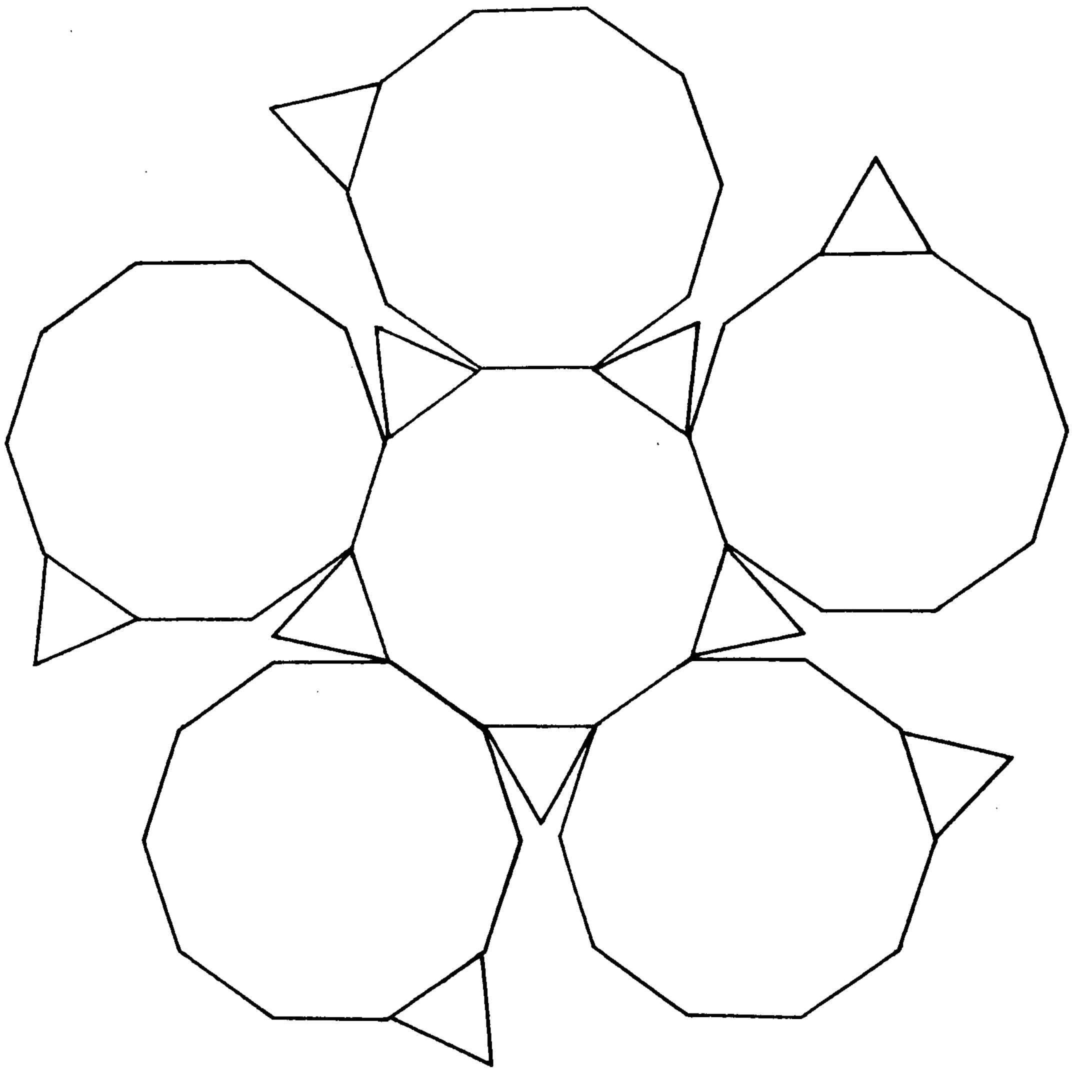


Figure 2.- Pattern for half of a truncated dodecahedron.

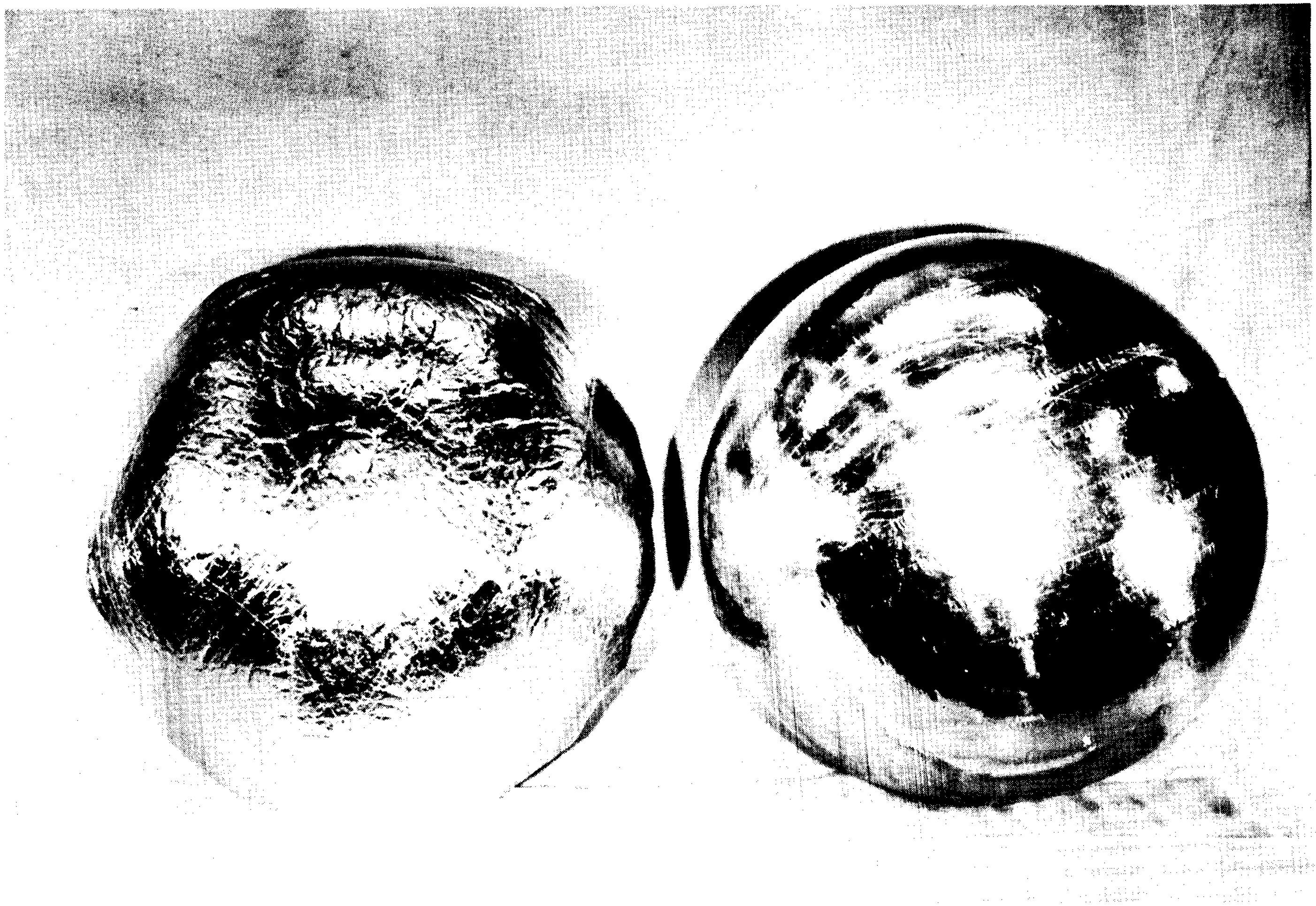
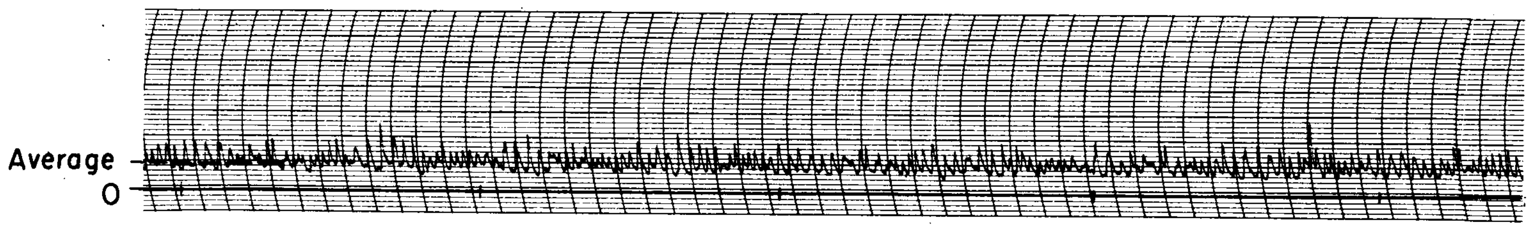


Figure 3.- Photograph of faceted model and comparison sphere. L-58-276a

(a) Faceted model.



(b) Sphere.

Figure 4.- Galvanometer trace of light reflection from rotating models.

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